Missouri Department of Natural Resources (DNR) and U.S. Environmental Protection Agency (U.S. EPA)

Contamination Characterization through Airborne Hyperspectral Imagery Pilot Project

Site Development Workshop - April 7, 2005 Report

Overview

The Missouri Department of Natural Resources, the department, received an Environmental Protection Agency (EPA) Office of Solid Waste and Emergency Response (OSWER) grant for a Pilot Project to evaluate Hyperspectral Imagery (HSI) applications to characterizing chemical contamination. The project identifies and evaluates potential applications of the Civil Air Patrol's (CAP) new hyperspectral imagery (HSI) airborne sensor to real-time support for the department's Environmental Emergency Response (EER) and local emergency responders, wide-area characterization or field screening of chemical contamination and analysis of other environmental problems. CAP's HSI system, Airborne Real-Time Cueing Hyperspectral Enhanced Reconnaissance (ARCHER), will be deployed in 16 locations around the continental U.S. in mid-to-late 2005. The Pilot Project is in the early stages of identifying potential environmental applications for evaluation and developing a database of sites for HSI collection.

On April 7, 2005, the department held a Site Development Workshop at the Truman Building, Jefferson City, for federal and state agencies to exchange information on requirements and potential applications of HSI with ARCHER's project personnel. The workshop included a briefing on EPA's Airborne Spectral Photometric Environmental Collection Technology (ASPECT) system. ASPECT is a multi-spectral Infrared imaging system that characterizes airborne contaminant plumes.

The Workshop began with a description of remote sensing and HSI by Dr. Clayton Blodgett, Univ. Missouri Columbia, the Pilot Project's HSI analytical lead. Col Drew Alexa, HQ CAP, Director Advanced Technology Group, followed with an overview of the ARCHER HSI system, its designed missions and the results of operational testing. Six department Project Managers (PM) then presented overviews of their contaminated sites and information requirements, with discussions on potential applications of HSI and ARCHER to their requirements following each presentation. Lt Col (Dr.) John Kershenstein, CAP/Chief Scientist Naval Research Laboratory, ARCHER design group, joined the site discussions via conference phone. The exchange of information about site contamination, potential HSI analytical applications and ARCHER capabilities was informative. It provided the PMs and Pilot Project team with an appreciation for ARCHER's capabilities, and a better understanding of applications that have a higher potential for success, and a greater opportunity for expanding ARCHER's support to states and federal agencies.

ARCHER appears to have an immediate application to several EER and solid waste management area search requirements, and a potential to support several on-going state and federal environmental studies. The sensor does not cover the Mid and Thermal IR bands, and will have limits on applications that require those bands. An example may be identifying illegal discharge points or seeps in waterways, and locating tire dumps based on reflected heat from the tires. The Project will need to focus on achievable applications, now that there is a better understanding of ARCHER's capabilities.

An ASPECT briefing followed the ARCHER discussions, presented by Mr. Tim Curry, EPA Region VII. ASPECT is an operational asset for EPA's Emergency Response team, as well as state and federal emergency responders. Its multi-spectral sensor has 16 Infrared (IR) detectors, and identifies airborne contaminants by their IR signature. ASPECT was used to define underground hot areas in a landfill fire in southwest Missouri, and has limited applications to ground and water analytical requirements.

The remainder of the Workshop was open to discussions of site conditions and HSI applications by attendees. Mr. Jim Felkerson, USGS, described an Oak Decline study in southwest Missouri, which HSI could potentially support.

Hyperspectral Imagery Pilot Project

OSWER Grant. EPA OSWER sponsors a variety of innovative projects twice yearly. The project themes for fall 2004 included homeland security initiatives related to chemical emergency prevention preparedness and response. The department's Hazardous Waste Program (HWP) proposed evaluating airborne HSI to expand routine statewide characterization of chemical contamination, and support environmental emergency response. CAP is acquiring 16 aircraft with HSI sensors for their homeland security, search and rescue, disaster relief and counter drug missions.

Project Objectives. The overall objective of the Project is to identify environmental applications for CAP’s HSI sensor, and commercial HSI sensors, collect imagery of known contaminated sites using CAP's system, or a commercial airborne sensor with a similar spectral range, develop spectral signatures of the contamination, and assess proposed applications. The Project will also identify collection and analysis procedures that can be used with future CAP flights. Applications characterizing chemical contamination in support of real-time EER would be the highest priority. Other applications for wide area field screening or characterizing contaminated sites, assessing levels of contamination and determining the use of vegetation stress as an indicator of contamination will be evaluated, to the extent funding allows.

Follow-on Options. CAP, as an auxiliary of the U.S. Air Force (USAF) State Emergency Management Agencies (SEMA) under a USAF funded program. The department's EER could be supported through SEMA. If ARCHER has application and is cost effective for non-emergency environmental missions, the state or a joint state-federal agency Memorandum of Understanding (MOU) would need to be established with CAP to cover expenses and liability for its volunteer pilots. Some commercial airborne HSI sensors collect imagery in a wider spectral range than ARCHER, providing more signature information to distinguish similar materials. The Project may show that an application may require a commercial sensor. Because of the expense of commercial collection, cooperative tasking between states and agencies may be an option.

Project Phases.
Phase I - Research Existing Environmental Applications. This phase includes contact with universities, government agencies and commercial collectors to identify existing environmental applications.

Phase II - Develop Prospective Sites. This phase includes contact with state and federal agencies to identify contaminated sites and potential participants in the Project. The Site Development Workshop was part of Phase II, and held to provide information about HSI and ARCHER to state and federal PMs, and present a variety of sites to ARCHER personnel for potential imaging and evaluation.

Phase III - Collect Hyperspectral Imagery. The department has requested ARCHER missions for the summer and fall, if available.

Phase IV - Analyze and Report. University of Missouri remote sensing staff, through the Missouri Resource Assessment Partnership (MoRAP), will analyze the imagery and provide a report. PMs from selected contaminated sites will be invited to participate in the analysis.

Attachment 1 is the Pilot Project and Workshop overview briefing.

Hyperspectral Imagery and Remote Sensing

Hyperspectral Imagery. Images acquired in dozens to hundreds of narrow contiguous spectral bands, generally in the visible, and near, mid and thermal IR wavelengths. Every material has a unique spectral signature. The greater the number and narrower the bandwidth of detectors in a HSI sensor array, the greater the capability to distinguish materials, particularly those with similar spectral signatures. Resolution is also a factor. The larger the individual image pixel the more mixing or averaging of signatures and less opportunity to identify small quantities of specific materials of interest.

HSI Analysis. HSI can be analyzed by one of three methods.

Anomaly Detection - Little is know about the scene. The analyst identifies pixels that are uniquely different from the background, and these are flagged as anomalies.

Target Detection - The spectral signature of the target material is known. The analyst matches pixels in the scene with the known signature, or signatures from a library. The assumption is that the pixels containing the target are "pure".

Material Identification - A library of spectral signatures exists for the materials in questions. The analyst compares the materials in sub-pixels with the library spectra. Sub-pixels are known as endmembers, and represent the pure material.

Attachment 2 is the Hyperspectral Imagery presentation by Dr. Blodgett.

CAP's ARCHER Airborne HSI System

Concept and Capabilities. ARCHER was custom-designed to support CAP's current and future missions of Search and Rescue, Counter Drug, Disaster Relief and Homeland Security. It performs automated, on-board HSI analysis by: matching collected spectral data with a library of signatures or filters; identifying anomalies or spectral data that doesn't match or belong in the background; and, a future capability, matching a current scene with previous imagery to identify changes. ARCHER will not detect targets through solid materials, underground, under snow, under water or at night.

System Components. ARCHER has a 60 + HSI detector array, that collects 30GB/hour of data. The system has a GPS/INS module for geo-referencing the imagery and a High-Resolution Imagery (HRI) black and white camera for visual reference and overlay of HSI data. The system includes a ground Trac Interface that displays the actual flight path overlayed on a chart. A handheld field spectrometer provides spectral signatures for automated match filter analysis. Satellite communications allow delivery of image clips to on-scene personnel via e-mail.

Operations/Target Detection. ARCHER normally conducts 2-3 hour missions, a crew endurance limit. Imagery is available on-board the aircraft for analysis on a large screen display. There is also a ground station for in-depth analysis. The aircraft operates at 2,500ft elevation, 100 knots, with a field of view across the flight path of 1/2 km and a 1 square meter spatial resolution. The HRI camera has a 0.3 square meter resolution. ARCHER can be flown as low as 1,000 ft elevation, with an increase in resolution. However, the area coverage is less and the increase in detection limits is questionable.

Deployment. Sixteen ARCHER systems will be deployed in CAP regions around the country. Deployment is expected to begin in mid-2005.

Attachment 3 is the ARCHER brief presented by Col Drew Alexa, CAP, Director Advanced Technologies & ARCHER Program Manager.

Overview of Contaminated Sites

Six Project Managers (PM) followed the ARCHER brief with an overview of their sites and information requirements. The site presentations are Attachment 4. The following are highlights of the presentations and follow-on discussions.

Wright City Landfill. The landfill has several seeps into an adjacent creek and a significant problem with methane gas emanating from areas outside the landfill. Project objectives would include determining if HSI could locate seeps and provide indications of where methane may be venting. ARCHER may be able to identify seeps if there is an isolated change at the surface of the water or creek bank. The methane gas would not be detectable, but effect on vegetation may be.

Potosi Area Mining. Abandoned mines and mining contamination in residential areas is a significant problem throughout southern Missouri. Project objectives would include determining if and to what level HSI can detect contamination from ore dust along haul roads and in residential areas, locating abandoned mines and related activity, and determining the ecological impacts of mine runoff on aquatic and terrestrial environments. Similar commercial HSI sensors have been used to characterize the distribution of mine tailings for high concentration levels. ARCHER, with its higher resolution, may be able to determine the extent of contamination at the lower concentrations found in residential areas. The target detection capability may be able to locate abandoned mining activity, particularly in areas not easily accessible to field personnel.

<u>Big River Mine Tailings Contamination</u>. Mine tailing dams and tailing piles near waterways have added extensive contamination to riverbanks and bottoms. Several studies are underway to characterize the extent of contamination. Project objectives would include determining if HSI can detect and define the extent of metals contamination in soil and downstream sediment, and can locate contamination hot spots in soil and sediment. As with the Potosi Area study, ARCHER's higher resolution may allow characterization of contamination at lower concentrations.

<u>Lake City Army Ammunition Plant (LCAAP) Surface Contamination</u>. LCAAP is a National Priority List (NPL) environmental cleanup with lead sludge disposal areas, solvent pits and piles of ammo cans and other debris site-wide. Project objectives would include defining the extent of sludge distribution, use signatures of known solvent pits to locate other solvent dumpsites, identify seeps from an abandoned landfill, and map debris sites. ARCHER should be able to locate debris sites with its existing anomaly detection capability. Characterizing the extent of lead sludge contamination would be a similar initiative to the mining area efforts.

<u>Hematite Radioactive Site Waste Pits and Surface Contamination</u>. Uranium was processed at a plant in Hematite. Uranium dust contaminated a large area around the site and solvents and other materials were disposed of in ponds and landfills on site. The radiation levels from the Uranium dust have been mapped for the site, but not off-site. The locations of the ponds and landfills are generally known. Project objectives would include identifying the signature of the surface and vegetation in areas of known uranium contamination and extend characterization to unsampled areas. It would include identifying additional waste ponds on or around the facility. ARCHER participation would be similar to mining dust and sediment studies. EPA ASPECT aircraft has a gamma detector. Tim Curry, ASPECT, expressed an interest in evaluating the sensor using the known radiation levels at Hematite.

<u>Illegal Tire and Waste Dumps</u>. Illegal dumping of tires and other solid waste occurs around the state, and pose a significant health risk. They are generally not found unless reported. Project objectives would include locating tires and waste dumps under vegetation and in remote areas. ARCHER's HSI anomaly detection capability may be able to detect waste dumps, but tires and other black objects do not have a signature in the visible and near-IR bands. ARCHER's HRI camera should provide the resolution to spot waste and tires in the open.

<u>Environmental Emergency Response (EER)</u>. Contaminant spills from tractor-trailer accidents occur daily. Most are contained quickly by local responders. Larger spills, such as derailments into waterways or accidents at industrial sites are more difficult to contain, and generally involve the department's EER personnel. The EER watch will be notified of ARCHER missions. In the

event an incident occurs in an area where ARCHER is imaging, ad hoc collection will be attempted. The project objective will be to evaluate the procedures and potential information that ARCHER can provide to EER personnel.

Flood-Borne Industrial Contamination. This presentation was not briefed, but is included for information. St. Louis, Kansas City and other large cities along the Missouri and Mississippi rivers had large industrial complexes in the floodplain. The 1993 flood inundated many industrial areas along the river spreading a wide variety of toxic and hazardous chemicals, and washing away hazardous material containers. The volume of water and speed of the 1993 flood diluted much of the contamination. However, contamination could be washed into backwater areas, and containers deposited along the river. EER personnel are faced with identifying hot spots of contamination and containers of chemicals, propane tanks and other hazardous objects. ARCHER's anomaly detection capability could locate containers. HSI may be able to identify concentrations of chemicals from a signature library, or identify deposits of materials that differ from background.

Tyson Valley Powder Farm Small Arms Range. This presentation was not briefed, but is included for information. Explosives, solvents and metals were disposed of up gradient of a river and floodplain at Tyson Valley. Contamination leached into the ground water and has been transported down gradient into the floodplain. Monitoring wells generally define the contamination plume. If the contamination has an affect on vegetation, particularly deep-rooted trees, HSI may provide additional information on the extent of the plume.

USGS Oak Decline Study. The U.S. Geological Survey (USGS) is conducting a study of oak decline in southeast Missour, focusing on the Potosi and Salem Ranger Districts. The study uses HSI from a commercial sensor to evaluate spectral response as a tool to measure pre-stress indicators in oak trees. However, more data, with better resolution, is needed to continue the study. This Project will collect HSI to support the Potosi area lead mining assessment, and will provide copies of the imagery to USGS for their study.

EPA's ASPECT Airborne Contamination Detection System

Concept and Capabilities. EPA's Airborne Spectral Photometric Environmental Collection Technology (ASPECT) provides standoff hazard detection with direct support to first responders. It is the only operational national asset providing remote chemical/radiological detection in near real-time. ASPECT produces geo-registered wide-area images of chemical plumes, cross-sectional plots of the plumes, thermal and radioactivity contouring, and photography/video of the scene. The chemicals are identified by their Infrared (IR) signatures, which are developed through laboratory and live testing. The signatures are maintained in the system's onboard analytical workstation for automated identification. Only six - twelve spectral signatures are currently in the library, but the ASPECT program will eventually expand to the 200 most common industrial chemicals of concern. The system identifies the chemical, and provides a calculated volumetric concentration (parts per million times meter thickness).

System Components. ASPECT has three primary sensors, an Infrared (IR) line scanner (mid and long wave bands), a high-speed spectrometer, and a gamma-ray spectrometer (4x4x16 NaI with Berkeley Nucleonics SAM 935 Gamma Ray Spectrometer).

Operations. An operator onboard the aircraft analyzes the sensors data as it is collected and annotates the content and concentration of chemicals in the plume on a geo-rectified digital image showing the extent of the plume. The data can also be provided in other formats. ASPECT carries a data and radio communications case that is air dropped to emergency responders on the ground. The aircraft remains on station for 4-6 hours, periodically updating the content and concentration of chemicals and extent of the plume, and transmitting the information to the ground. The IR systems are not limited to daylight hours. ASPECT can also be used for non-emergency thermal and radiological mapping tasks, at a cost of $700-$800/hr flight time. ASPECT normally operates at 2,000 ft AGL, with a cruise speed of 180-200 kts.

Deployment. The ASPECT program currently has one aircraft based in Dallas, TX. The aircraft and crew are on 1 hr standby, and can be almost anywhere in the lower 48 states within 9 hrs. Most of the 48 states, from Miami to Salt Lake City, are within 6 hrs response time. Additional aircraft may be deployed in the future.

Attachment 5 is the ASPECT brief presented by Mr. Tim Curry, EPA Region VII, Emergency Response Team.